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Tektites as Lunar Volcanic Ejecta

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Abstract - Most tektites have differentiation ages under one billion years; the lunar surface, from Apollo 11, is mostly several billion years old. Most of the younger parts (the maria) are basaltic. Hence either tektites do not come from the lunar surface or they come only from some very restricted regions. The aerodynamic data, the evidence from diffusion rates, and the successful prediction of lunar H_2O and Ni, point to a lunar origin. Verbeek's original suggestion, that tektites are lunar volcanic ejecta, will explain the selectivity. It also explains the paradoxical success of the K-Ar dating methods.

In 1943, H. H. Nininger [1] suggested that tektites might have been launched from the moon by meteorite impact. Supporting this idea, Chao [2] and his coworkers found nickel-iron spherules as rare constituents of some tektites; El Goresy [3] deduced from the presence of zircons decomposed into baddeleyite and silica that some tektites have been exposed to temperatures on the order of 1700°C, which is too high for terrestrial volcanics; Walter [4] found coesite, an impact produced polymorph of silica, in some tektites of the Muong Nong

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type. These indications have convinced most students of the subject that tektites are the products of impact.

That they are extraterrestrial is indicated by the aerodynamics studies of D. R. Chapman and his coworkers [5], who have interpreted the morphology of the australites in particular in terms of ablation of glass spheres in hypersonic descending flight. In an unpublished study based on a computing routine put together by J. D. Warmbrod [6], working with E. W. Adams, it was found, in confirmation of one part of Chapman's results, that the amount of ablation observed in tektites could be explained only by either

a. velocities in the neighborhood of satellite velocities but at entry angles of 5° or less to the horizon,

b. velocities in the neighborhood of the earth escape velocity. Neither is plausible for materials coming from the earth.

An extraterrestrial origin is also indicated simply by the fact that tektites often consist of relatively homogeneous and bubble-free glass, in pieces up to a decimeter in diameter, not chemically identifiable with terrestrial igneous glasses. It is difficult to explain these glasses as the result of impact on terrestrial sedimentary rocks, because time is required to eliminate water and the resulting bubbles [7]; time is also required to homogenize the glass [8]; for both processes it appears that impact does not provide the necessary conditions. From the observational standpoint it is significant that of the 60 impact structures that have been studied during the past 10 years [9] not one has been found to have tektites physically associated with the impact ejecta.

If tektites are extraterrestrial, it has long been agreed that the absence of cosmogenic nuclides [10] and cosmogenic fission tracks [11] indicate such a brief period of time in space as to rule out sources further away than the moon.

The low content of nickel, cobalt and other siderophile elements in tektites suggested that the moon would be found deficient in these elements, a prediction which is apparently verified [12]. The deficiency of water, alkalies, and other volatile elements in tektites (as compared with terrestrial acid rocks) suggested that the moon would also be found deficient in volatiles; it seems to be so.

The implication from tektite studies that the moon may have some acid volcanism is supported by some morphological studies of the moon [13]. These formations are not common, however, and the suggestion of O'Keefe [14] that the maria would be found to be surfaced with acid ash flows is false.

Despite these successes of Nininger's hypothesis, the recent measurements from Apollo 11, and at the same time on the tektites have presented a very serious difficulty. On the one hand, the lunar analyses have shown that the lunar surface is basic in its chemical constitution, at least in the maria [15, 12] and that Mare Tranquillitatis is at least three billion years old [12]. The latter point is important because it is clear from morphological evidence that the maria are more recent than nearly all the highland material; and highland material covers 5/6 of the moon. Optical data by Hapke [16] and Salisbury et al. [17] extend the chemical inferences from the Surveyors and Apollo to much wider areas of the lunar surface. On the other hand, it has long been clear from Rb/Sr dating that some tektites are derived from material which differentiated not later than -300 m.y. [18]; more recent information suggests that the moldavites may have differentiated after -100 m.y. [19].

The difficulty is thus that the hypothesis of the origin of tektites by impact on the moon seems to demand a source in recent acid rocks, while the evidence indicates that the moon consists for the most part of ancient basic rocks.

In 1897, R. D. M. Verbeek [20, 21] offered what may be a solution to this problem. From his studies of the 1883 eruption of Krakatoa [22], he concluded that a similar eruption on the lunar surface would have imparted velocities of as much as 2.3 km sec^{-1} to a part of the ejecta, so that it would have escaped from the gravitational field of the moon, and some would have reached the earth. This hypothesis explains at once why tektites are unrepresentative of the lunar surface in their major elements, and yet are useful indicators so far as the minor elements are concerned. A similar argument has been made by Classen [23].

Specifically, it was pointed out by van Padang [24] that although Krakatoa produces both acidic and basaltic lavas, the two great eruptions occurred when the lava was highly silicic (in agreement with the majority of violent eruptions in other volcanoes). The Verbeek hypothesis may explain another curious fact, namely the close relation in time and chemical constitution between the Ivory Coast tektites and microtektites and those of the Australasian strewn field [25]; the relation may be simply the result of two successive eruptions from a single lunar volcanic complex.

Verbeek's idea also explains the disturbingly close relation between the K-Ar ages of tektites and their stratigraphic ages. In the laboratory, it is found very difficult to expel all the argon from a tektite [26]; it requires at least 20 minutes at 2000°C [27]. In nature, tektites which sometimes contain inhomogeneities or other evidence of incomplete heating nevertheless yield good K-Ar ages. Most terrestrial impact glasses do not give good ages; how does it happen that lunar impactites, if that is what tektites are, have been thoroughly outgassed in the few seconds of impact heating?

It is conceivable that microtektites represent glassy droplets from the actual eruption which sent the tektites to the earth. The larger tektites may represent fragments of wall rock, formed in at least some cases by welding of similar droplets [28]. Owing to the higher melting point of the lunar materials, it is clear that the volcanic temperatures would be higher than those in terrestrial eruptions. It may be that conditions of temperature and oxygen pressure would be such as to bring about differential volatilization among the spherules, in accordance with the evidence brought forward by Walter [28]. On this hypothesis, the larger tektites might represent deposits from earlier eruptions of the same cycle as that which sent the tektites to the earth.

Verbeek's data for Krakatoa [22] do not establish a strong case for velocities over 1 km sec^{-1}. For gases escaping from a chamber into a vacuum, however, the following formula from Oswatitsch [29] gives the limiting velocity:

$$v_{lim} \sqrt{2 C_p T}$$

where C_p is the heat capacity at constant pressure, (tabulated by Oswatitsch for water) and T is the absolute temperature. Assuming water, and a temperature of 1300°C (1573°K) it is found that the limiting velocity is 2.9 km sec^{-1}. If the water is partly reduced, yielding some H_2, this figure may be too low.

The above suggestion concerning the volcanic launching of tektites does not necessarily conflict with the calculations of Chapman [30] indicating that Tycho may be the source of the Australasian tektites. It does suggest that in addition to a possible history of impact, Tycho may also be the seat of recent acid volcanism, perhaps brought on by an impact. It should be remembered that the rays of Tycho do not radiate from the center of the crater, but from points on the rim.

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